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(54) Title: METHOD AND SYSTEM FOR EXTRACTING SPINE GEOMETRICAL DATA

(57) Abstract: A method for extracting geometrical data from a 2-D digital image of the spine, comprising steps for determining spine outlines, endplates and corners wherein: digitizing the spine center line a nd end points; constructing a 2-D image band, referred to as Rub ber-Band, whose center line is a spline representing the spine center line, and unfolding said Rubber-Band for constructing a 2-D Rectangular-Band; processing the 2-D Rectangular-Band image data in order to estimate best paths going through selected points for determining the spine outlines, then the endplates based on the found outline data and the corners at the intersection of the outlines and endplates.

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Method and system for extracting spine geometrical data

The invention relates to an image processing method for extracting geometrical data of a spine image. The invention finds its application in medical imaging.

5   A segmentation method applied to the spine is already known of the publication "Digital Radiography Segmentation of Scoliotic Vertebral Body using Deformable Models" by Claude Kauffmann and Jacques A. de Guise in SPIE Vol.3034, pp.243-251.This publication describes a computer segmentation method based on the active contour model (g-snake) and using a prior knowledge. This method is adapted and used to

10   detect automatically the contour lines of each vertebral body independently in digital radiographs of the scoliotic spine. These contour lines are used to identify correspondent anatomical landmarks for the 3D reconstruction of the scoliotic spine using a bi-planar technique. The steps comprise: constructing a standard template for each kind of vertebrae (thoracic or lumbar), performing three best fits of the appropriate template on the spine

15   radiograph, g-snake energy minimization, selection of a best contour for each vertebra individually, and anatomical landmark extraction (including corners and spine center-line points). Previous steps of digitization of the spine centerline and acquisition of a prior knowledge including the height and width of the standard template are first performed.

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        It has been found that the method known of the cited document necessitates many interactive corrections, because the actual "best fit" is difficult to select among the "three best fits".

        The present invention has for object to propose a method to extract spine data

25   that is easier to carry out and that is more robust. An image processing method that solve this problem is claimed in Claim 1. The present invention has particularly for object to propose a method to extract the spine outlines, the spine endplate projections and the corner projections in an X-ray image of a number of adjacent vertebrae of the spine. An image processing

method to solve those problems is claimed in dependent Claims. An imaging system, an X-ray apparatus and a computer program product are also claimed to carry out the method.

The extracted geometrical data permits of providing information appropriate to help diagnosing scoliosis even on a single 2-D image. Said data also permits of three-

5   dimensional image reconstruction of the spine from two bi-planar images using a technique of geometric modeling. Three-dimensional images of the spine particularly help diagnosing scoliosis because said disease is a 3-D deformity of the spine.

The invention is described hereafter in detail in reference to diagrammatic figures, comprising:

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Fig. 1A, Fig. 1B, Fig. 1C representing a vertebra in various perspectives;

Fig. 2A and Fig. 2B showing the optimal landmarks of a vertebra, respectively in frontal and lateral views;

15   Fig. 3A, Fig. 3B, Fig. 3C and Fig. 3D illustrating the transformation of a Rubber Band of a frontal image into a Rectangular Band;

Fig. 4 which is a Gradient Map of the ROI in the (u, v) cartesian referential;

Fig. 5A representing a Gradient Cost Function for a spine outline detection; and Fig. 5B which is a Gradient Cost Map of a ROI for the lower part of Fig. 4;

20   Fig. 6A illustrating the average width (vertically) and standard deviation from statistical anatomical data of the vertebrae (horizontally); Fig. 6B illustrating the endplates widths and vertebral lengths normalized by the length of the patient spine (thin line) and a derived polynomial of the third degree (thick line); Fig. 6C which illustrates a cost function for the detection of spine outlines;

25   Fig. 7 showing a centerline and spine outlines on a frontal view;

Fig. 8A showing respectively a zoom part of the Cost Map before and after the introduction of a Guide-Point;

Fig. 9 illustrating a proposed Gradient Cost Function for Endplate Detection;

Fig. 10 showing the Cost Profile in the upward direction (thick line) for

30   finding up-endplates, and in the downward direction (thin line) for finding down-endplates;

Fig. 11A and Fig. 11B showing theoretical location and standard deviation to find the endplates in function of the vertebra number and the inter-vertebra number;

Fig. 12A illustrating an example of initializing a cost matrix; Fig. 12B showing a bell-shaped Cost Function;

Fig. 13A and Fig. 13B showing the results of the outlines and endplates detection before and after the introduction of guide-points;

Fig. 14 illustrating a final result;

Fig. 15 illustrating a functional block diagram of a medical diagnostic imaging system and of an apparatus for carrying out the method.

The invention relates to an image processing method for extracting geometrical data of the spine, in order to localize specific elements of the spine in spine images, for studying spine deformities. The specific elements are preferably endplate and vertebrae corner projections. Referring to Fig. 1A to Fig. 1C, which are perspective views of a vertebra, the vertebra shows: a body 7 that is substantially cylindrical with flattened elliptic bases 1, 2 called endplates (Fig. 1A, Fig. 1C); the vertebra body defines the spine axis and the shape of the vertebral discs; a spineous process 4 located in the plane of symmetry of the vertebra (Fig. 1A, Fig. 1B); two transverse processes 3 (Fig. 1A, Fig. 1C); two pedicles 5 located at the bases of the vertebral arches (Fig. 1A, Fig. 1B); the pedicles define the intrinsic rotation of the vertebra around its axis. The localization of these elements is based on the detection of landmarks, which are elements of a spine image having anatomical relevance. A frontal and a lateral views of the spine are sufficient to build the 3-D model of the spine. Six optimal landmarks (for visibility and quality of reconstruction) are selected, as represented in the frontal image shown in Fig. 2A, and in the lateral image shown in Fig. 2B. These landmarks are the extremities of the projection of the vertebra body, which are the corners A, B, C, D, A', B', C', D' of the vertebra shown in Figs. 2A and 2B; the position of the inner points E, F of the projection of the pedicles, further on called pedicle landmarks, shown in Fig. 2A. Not all the spine may be of interest. A Region Of Interest ROI of for example 16 adjacent vertebrae may be defined.

The method comprises steps of:

I) Acquisition of Image Data comprising sub-steps of:

1) Acquiring 2D image data of the spine, preferably of a frontal image and/or of a lateral image of an examined patient. Fig. 3A shows a frontal view formed by x-ray imaging, as an example. Each point has a luminance intensity and coordinates in a cartesian referential x, y.

2) Manual operation of the user, to enter two kinds of guiding data specific to the patient: design data of a "spine centerline" performed on the frontal and/or lateral views;

and initial anatomical data of the spine. Referring to Fig. 3A, the centerline data comprises center points located at the centers of the vertebrae in a 2D image and first and second end points A', B' located at the extremities of the spine. The centerline is designed passing through these points. The initial anatomical data comprises the height and reference number

5   of the first and last vertebrae in the Region Of Interest ROI and the total number of vertebrae, for example 16, represented on said ROI. After this manual operation, the spine outline detection is further done automatically using the stored image data, the centerline data and the anatomical data. These further automatic steps of the method are not performed on the original 2D image, but instead on a transformed 2D image.

10   3) Performing an Image Transformation. The Original Image is transformed by first constructing a Rubber-Band, and by secondly unrolling the Rubber-Band for constructing a Rectangular-Band. These operations comprise:

                digitizing the spine centerline and end points, as illustrated by Fig. 3A showing the spine original frontal image, using the points of the vertebrae given by the user.

15   Hence, the centerline is a "spline" going through the centers of the vertebrae from the first end point A' to the second end point B';

                building a 2-D image band, called "Rubber-Band", whose "centerline" is the spine centerline and whose outlines are parallel to the spine centerline, as illustrated by Fig. 3B. This Rubber-Band has a fixed width larger than the actual width of the spine in the

20   Region Of Interest ROI and a length equal to the predetermined length of the spine centerline in said region, from A' to B'. The extremities of the outlines of the "Rubber Band" are defines by points P'1-P'3 and P'2-P'4;

                forming a transformed image band, called "Rectangular-Band", as illustrated by Fig. 3B. This Rectangular-Band is constructed by unfolding the Rubber-Band so as to

25   straighten the "centerline" and make the outlines P1-P3, P2-P4 of the Rectangular-Band parallel to said straighten "centerline". The length of the centerline AB and of the outlines P1-P3, P2-P4 of the Rectangular-Band are equal to the length of the centerline A'B' and of the outlines P'1-P'3, P'2-P'4 of the Rubber-Band.

                calculating the coordinates (u, v) of the points of the Rectangular-Band. The

30   Rubber-Band has a cartesian referential x, y in Fig. 3A and Fig. 3C; and the Rectangular-Band has a cartesian referential u, v in Fig. 3B and Fig. 3D. In the Rubber-Band of Fig. 3A and Fig. 3C, a given point Q' has first cartesian coordinates x, y. Said given image point Q' has also curvilinear coordinates, which are the algebraic distance $v=Q'Q_0$ from the point Q' to the spline centerline A'B', and the curvilinear measure $u=A'Q'_0$ along the spline. In the

Rectangular-Band of Fig. 3B, the cartesian coordinates u, v of the corresponding image point Q are defined by said curvilinear coordinates i. e by the measure $QQ_0 = v$ of the distance of said Q to its projection point Q_0 on the straighten centerline and by the measure $AQ_0 = u$ from said projection point Q_0 to the end point A of the straighten centerline, labeled origin.

5   The centerline AB and the orthogonal line passing through said origin A, constitute the actual referential u, v of the Rectangular-Band.

determining the intensity of the points in the Rectangular-Band: Referring to Fig. 3C and Fig. 3D that respectively illustrate a part of a Rubber-Band and a corresponding part of a Rectangular-Band, the Rectangular-Band is scanned, for example according to a

10   standard scanning technique, and a Correspondence Table is favorably used for determining the luminance intensity of each scanned point from the luminance intensity of a corresponding point that is looked for in the Rubber-Band. The Correspondence Table is built by calculating the coordinates x, y, in the Rubber-Band, of the point Q' corresponding to the given point Q of coordinates u, v, considered in the Rectangular-Band. The intensity of each

15   point of the Rectangular-Band defined by its coordinates in the u, v referential is determined from the intensity of the corresponding point in the Rubber-Band defined by its coordinates in the x, y referential. The coordinates (x, y) of the point Q'(x, y) together with its luminance intensity are stored in the Correspondence Table for further automatically determining the luminance intensity to apply to each scanned point Q(u, v) in the Rectangular-Band. The

20   Rectangular-Band outlines are also determined in the u, v referential from the x, y referential.

Remark: By entering the centerline, the length of the spine is defined. This information is used to adapt the method of the invention to the current patient. It is equally used for small and high patients; it does not depend on the patient size.

Remark: The image processing method is further on uniquely performed in the

25   transformed image constituted by the Rectangular-Band of Fig. 3B. In particular, this operation of spine outline detection is performed in the Rectangular Band.

Remark : In the detection of the spine outlines, different problems are encountered. As shown in the frontal view of Fig. 3A (or in a corresponding lateral view), the mean gray level is not the same in the high and low parts of the spine image due to the

30   superposition of other organs such as the ribs attached to the thoracic vertebrae that interfere in the edge extraction. Smooth lines are looked for, but the images show the sides of the vertebra having numerous local curvatures with the corners emerging at the extremes and there is a high contrast in the middle of the height of the vertebra (where there are the pedicles) and a lower contrast on the corners. So, smoothing the lines must not be strictly

performed for not smoothing out the corners. The user criteria must be accepted as the right ones. Thus, any information entered by the user must overrule the other. The user is always allowed to modify the final results.

II) Semi-automatic Detection of the spine Outlines on a 2-D image by:

5   1) Estimating an Outline Cost Map by:

A) Forming a Gradient Cost Map including:

Forming a Gradient Map by extracting the gradients in the rectangular Region of Interest ROI, in the u, v referential. For detecting the outlines of the spine, gradients whose values are maximum in a direction orthogonal to the vertebral line (v direction) are looked

10   for. In Fig. 4, the brighter zones indicate a higher value of the gradient. The gradient values are not discretized, being preferably the actual calculated values. The gradient values are normalized to account for contrast difference along the spine, as appears from the view of Fig. 3A. To perform this step, windows smaller than the ROI are considered. In each window, the gradient values, from the lowest to the highest gradient values, are re-scaled in

15   order to spread over a larger given predetermined range that is the same for all windows. Using this technique, the gradients are both enhanced and normalized. The mean values of the gradient values are the same in the whole image; also, the range of the gradient values is unique.

Constructing the Gradient Cost Map by assigning a Cost Function to the

20   gradients, referred to as Gradient Cost GC. This Gradient Cost function allows to attribute the lowest costs to points having the highest gradient values, and the highest cost to points having the lowest gradient values. A proposed function is:

Gradient Cost $= 1 / (\text{Gradient}^{0.5})$

This function is featured in Fig. 5A, where GC is the Gradient Cost, MAX(GC) is the

25   maximum of Gradient Cost and MIN(GC) is the minimum of Gradient Cost, MAX(G) is the maximum of the gradient values G in the range determined by the normalization step and NL is the Noise Level. The Gradient Cost Map is deduced from this Cost Function. Fig. 5B shows a Gradient Cost Map, which corresponds to the lower part of Fig. 4 and the left part of Fig. 3B; the darkest zones represent the minimum costs.

30   B) Constructing a Prior Knowledge Cost Map by:

Entering prior knowledge data: As the gradient information gives several possible paths for one outline, prior knowledge is incorporated from a statistical database. Fig. 6A illustrates this kind of possible prior knowledge: W(v) is the average vertebra width

in the v direction in pixels, and DW is the standard width deviation, N is the number of

vertebrae along the u-axis (16 vertebrae).

Creating an adaptation function: Given the centerline, the u-axis is normalized

to the actual length of the patient spine. The average value of the width W(v) in the v

5   direction permits of determining the average distance D(v) of the corners of the vertebrae

with respect to the centerline, which adapts this average data to the current spine length and

assigns a distance to the centerline for each point of said centerline in order to locate the

outlines, as illustrated by the thin line curve of Fig. 6B. A polynomial of third degree is

further determined from the thin line curve of Fig. 6B and shown on the same Fig. 6B

10   represented by a thick line. This polynomial is an adaptation function that interpolates the

distance values of the vertebra corners to the centerline for the whole patient spine. Hence,

for the left and right outlines, adapted predetermined outlines are deduced that are labeled

Prior Knowledge Outlines.

Defining a Prior Knowledge Cost Function: based on the location of these

15   adapted predetermined outlines, a cost function is defined to favor the region of the image

where it is more likely to find the outlines of the spine. A Cost, labeled Prior Knowledge

Cost, is attributed to the points, said Cost being the lower the nearer the points are of the

predetermined outlined. A proposed Cost Function PKC for the detection of spine outlines is

represented on Fig. 6C. The value VPK is the point given by the Prior Knowledge of the

20   vertebra width and δv is the distance to it. The curve has a minimum in the region where it is

most likely to find the spine side.

Constructing the Prior Knowledge Cost Map: A search area around each of the

Prior Knowledge Outlines delimits the more probable position of the outlines. In each area,

the points with their Cost constitute said Prior Knowledge Cost Map.

25   C) Constructing the Outline Cost Map by adding the Gradient Cost Map and

the Prior Knowledge Cost Map. There has to be a trade off between the features of the image

described by the Gradient Cost Map and the Prior Knowledge Map. So, a weight may be

assigned to the Prior Knowledge Cost.

2) Using a DP Algorithm for finding the Outlines : Dynamic Programming

30   (DP) stages are carried out in order to determine the outlines using Energy Functions. This

kind of algorithm, which is a non-iterative method effective in contour detection, is not

described, as it is well known of those skilled in the art. This step has for a purpose to

determine the "most likely path" for the outline points. The points that are to be linked are

those that are most likely part of the spine sides. The Dynamic Programming (DP) algorithm

is used to calculate a lowest cost path going from a node to another to yield this outline path. The DP is performed in the (u, v) referential in the u direction. For each stage of the DP algorithm, one preferred v position is chosen. The Energy Functions used to calculate the lowest cost to find said best path comprise:

5   A Local Cost, which is found in the Outline Cost Map.

                      A Transition Cost, which imposes constraints on the path:

                      between a node and an adjacent node of the DP algorithm, the path cannot go further than one position both in u and v directions (at an angle of 45 degrees);

                      a high deviation of the curve is penalized with regard to the previous found
10   points. A gradual change is wanted on the slope of the outline, sudden changes are not wanted because that does not correspond to reality. So, the current point is wanted to depend on the path found so far. Hence, in order to perform this, an exponential window is defined in the path created so far, thus going back in the time (u axis). This window is used to extract an average value that will be used to define the Cost of Transition from one node to another.
15   This method allows local deviation of the spine outline (one corner that emerges) but keeps the line general smoothness. A short size of the window is preferably defined (the vertebra average height is a good value) to keep the curve rigidity and the square of the line slope found so far is integrated all over the window. For instance a Transition Cost may be:

$$\text{Transition Cost} = \overline{\text{slope}}^{\,2}$$

20   3) Introducing Guide-Points: User interaction is allowed at all steps of the process to iteratively correct the results. Fig. 7 illustrates the center line in black and the found Spine Outlines in white on thee frontal view. The results are quite good, but the user may still want to improve said results. A mechanism is provided to let the user introduce more information in order to change the results by adding further spine data points labeled
25   Guide Points. When the user modifies one point location, the method is carried out again in order to take advantage of the information provided by this modification and find a better result on the whole Region Of Interest ROI of the image instead of only locally, in the neighborhood of the modified point location. Guide points compel the found outlines to go through them. There are 3 kinds of Guide Points: sides, up-corners and down-corners.
30   "Sides" are points lying on the sides of the vertebra, while "up-corners" and "down-corners" correspond respectively to the upper corners and lower corners of the vertebra. When one Guide Point is added, it forces the points around said Guide Point to have a very high Cost value in order to create a minimum of the Resulting Cost Function in the Guide Point, thus imposing the Outline Path to go through said Guide Point. Fig. 8A and Fig. 8B show

respectively a zoom part of the Outline Cost Map before the introduction of Guide-Points and after the introduction of Guide-Points. The value of the Cost around the Guide-Point has increased (white line) while the Guide-Point keeps its value (black point). When the Guide-Points are introduced, the Prior Knowledge data must be up-dated in order to incorporate

5   these points to the previously defined Prior Knowledge Outline. This operation is performed by means of two recursive low pass filters (causal and anti-causal) and weighted interpolation. The method is further carried out from the beginning.

Outline Detection Results: The results of the spine outline detection are shown in Fig. 7. The method performs well without the user's interaction in most of the cases. The

10   user interaction allows for real-time user modifications.

III) Endplates detection comprising:

Integration of the detection of the outline and the endplates in the same process: According to the invention, the Endplates Detection depends on the Outline Detection. Based on this principle, information on the Outlines is used to detect the

15   Endplates, the location of the intersections of the Endplates and of the Centerline, and consequently the location of the Corners of the vertebra.

Remark : In the endplates detection, the problems are similar to those found in the outline detection relating to the varying contrast in the images: While on the thoracic vertebrae the contrast is very poor, on the lumbar vertebrae, the contrast is quite high. But the

20   shape of the endplate projection is an ellipse so that two lines are found where only one is expected. One of the worst obstacles is the presence of the pedicles too close to the edges. The gradient level is very high and in the dynamic programming the endplates may be attracted by the pedicles. Besides, the endplates must follow a rather straight line. On the frontal view the direction of the endplates is nearly orthogonal to the vertebral line. However,

25   on the lateral view, its inclination depends on its position along the center line.

The endplate extraction comprises sub-steps of:

1) Extracting the gradients for Endplate Detection and assigning a Cost Function to said gradient: The gradients of the image are extracted in a new Region Of Interest, labeled ROI', delimited by the previously found Outlines. In the detection of the

30   Endplates, it is looked for gradients whose values are now maximum in a direction parallel to the vertebral line (v direction), in the upward direction for the Upper-Endplate and in the downward direction for the Lower-Endplate. The gradients are assigned a Gradient Cost Function GC different of the one used in the spine Outline Detection to be used as Local Cost. A proposed Gradient Cost Function for Endplate Detection is illustrated by Fig. 9. The

decrease in the minimum value of the gradient implies a change in the weighing of the cost of the gradient, enhancing the straightness of the endplate.

2) Using a First Dynamic Programming Algorithm DP1, in the (u,v) referential. Using said DP1, and starting from each point of a found Outline of the spine (and for both sides), finding the best path to reach the spine center line. This sub-step is performed twice, using the Gradients calculated for detecting Endplates: first by following the upward edge gradient direction and secondly by following the downward edge gradient direction. This DP1 uses energy functions to calculate the cost of the path that are:

A local cost that is the cost associated to the gradients for Endplate detection,

A transition cost with the constraints that the cost of transition of one node to another is the same as the one used in the spine outline detection (the square of the average slope over an exponential window); and that between a stage and an adjacent stage of the DP1 algorithm, the path cannot go further than one position both in u and v directions (an angle of 45 degrees).

An extra-cost that penalizes the difference in the slope of the right and the left path of the endplate. This extra-cost is formed by summing, for both the upward and downward direction of the gradient, the costs of the left and right path. This extra-cost is used to enforce the smoothness of the curve on the centerline.

Two cost profiles are determined along the center line: one for the upward direction, labeled CP-UP-EP, that is a cost profile for finding the location of the up-endplates; and the other for the downward direction, labeled CP-DW-EP that is a cost profile for finding the location of the down-endplates. Two examples of the cost profiles for the two directions, obtained by this way, are shown in Fig. 10 (vertical axis graduated in pixels). Referring to Fig. 10, the arrows with solid lines show the minimum of the cost profile corresponding to the location of down-endplates DW-EP while the arrows with dashed lines show the minimum of the cost profile corresponding to the location of up-endplates UP-EP. The interesting minimum of the cost profiles are easily distinguished most of the time, but not in every case. Besides, a number of visible minimum are not interesting. The distinction between downward and upward edges is to be done to sort all these minimum.

3) Using a Second Dynamic Programming DP2 and prior knowledge in the extraction of endplates location comprising the selection of all the points of the center line that actually correspond to endplates.

A) User interaction: for introducing the first and last vertebra endplate locations, the number of endplates to find and their anatomical names (L1, L2, L3, T12..).

B) Labeling nodes: In the different stages of DP2, identifying points of the center-line, called nodes, with the endplate locations numbered from 0 (down-endplate of lowest vertebra) up to 33 (up-endplate of highest vertebra). From now on, this number is named "label" of the node. Thus, if the label of the node is even it corresponds to a down-endplate and if the label is odd it corresponds to an up-endplate.

C) Bringing prior knowledge: Referring to Fig. 11A, for each vertebra, the theoretical height H (in pixels) and standard deviation along the u-axis is given by a database in function of the number N of the vertebra. And referring to Fig. 11B, the average height h (in pixels) of the inter-vertebra disk is defined on the u axis in function of the inter-vertebra number IVN. All the points of this inter-vertebral interval are given a respective label. This operation permits of defining intervals, along the spine centerline, where it is probable to find an endplate, in the first and the second profiles of Fig. 10, and the standard deviations with respect to said intervals.

D) Extracting the endplates following an up-down direction, from upper vertebra to lower vertebra. When moving on the u axis, progressively the standard deviation of the previous endplates is accumulated. Thus, the interval of possible u for the last endplates is larger than the interval that would correspond to it, if only its own standard deviation were took into account.

As illustrated by Fig. 12A, a Cost Matrix is used for:

assigning a label of first endplate to the first node, and labeling progressively the nodes to the last endplate, thus determining by accumulating standard deviations, several nodes to said last endplate;

redefining the appropriate label to the last node by using the user information of the last endplate location and

correcting the labeling of the previous nodes accordingly by backtracking toward the first node.

Referring to Fig. 12A, the upper vertebra is T10 and lower vertebra is L4. The first label (up-endplate 13) is assigned only to one point called first node for the first endplate (information given by the user) while the other labels (down-endplate 12 to down-endplate 0) are assigned to an interval of points, thus determining by accumulating standard deviations, several nodes. So, several labels have been assigned to the last u-coordinate that corresponds to the up-endplate of the last vertebra, whereas the appropriate label that corresponds to the exact location of said last vertebra is already known from the information given by the user. A backtracking is started on the appropriate u-coordinate of the upper-

endplate of the last vertebra and the labeling of the previous nodes are corrected accordingly while performing said back-tracking toward the first node.

The energy functions used to calculate the cost of the path for this DP2 are:

A local cost, which is the value of the down-endplates cost-profile and up-
endplates cost-profile respectively for the nodes with label even and odd.

A transition cost, which is the cost associated to two nodes denoted by S1,and S2, having V1 and V2 as labels and which is very high if the transition is impossible [For instance: V2 (lower vertebra)>V1 (upper vertebra)] or equal to the value given by :

1/Fcost(S2, S1, sigma2, avS2)

where Fcost is a cost function returning a cost according to: the u-coordinate of the node S2 denoted by u(S1); the u-coordinate of the node S1 denoted by u(S2); the theoretical distance d2 between S2 and its predecessor endplate location denoted by avS2; the standard deviation of this theoretical distance denoted by sigma2. A bell shaped function Fcost is illustrated in Fig. 12B. The function shows a minimum cost when the distance between the endplates S1 and S2 is closer to the theoretical distance.

4) Adding Guide-Points : The results are illustrated in Fig. 13A with the center line in black, the outline and the endplates in white. There are three points where the algorithm is mistaken. In numbers 1 and 2, the gradient of the pedicles is stronger than the gradient of the endplates, whereas in number 3, the smoothness constraint of the outline has forced a wrong solution. The user is allowed to interact to modify the final results. One modification in one step of the method involves computing again the previous results to find an optimized solution. Fig. 13B shows the results on the image after the introduction of three guide points indicated by arrows. After the extraction of the endplates, in a phase of validation, the results of the DP are checked in order to determine whether the points given by the user have correctly been used.

IV) Detection of the corners of the vertebra.

The corners of the vertebra are to be found as the final extremes of the endplates, at the intersection of endplates and outlines, shown as white crosses on Fig. 14. Guide points can be introduced by the user on the up-corners or down-corners of the vertebra. After the introduction of a new guide point, the spine outline must be computed again because the corners guide points belong also to the outline. When one corner is introduced, the cost of the points around it takes a very high value in order to create a minimum in this guide point and force the path to go through it. Thus the curve of Fig. 10 is modified. It

becomes less noisy and the locations of the useful minimum are clearer. The steps of the method are repeated until the result is correct. A sample of final result is shown in Fig. 14.

Referring to Fig.15, a medical examination apparatus 150 comprises means for acquiring digital image data of a sequence of images, and a digital processing system 120 for
5   processing these data according to the processing method described above. The medical examination apparatus comprises means for providing image data to the processing system 120 which has at least one output 106 to provide image data to display and/or storage means 130, 140. The display and storage means may respectively be the screen 140 and the memory of a workstation 110. Said storage means may be alternately external storage means. This
10   image processing system 120 may be a suitably programmed computer of the workstation 130, or a special purpose processor having circuit means such as LUTs, Memories, Filters, Logic Operators, that are arranged to perform the functions of the method steps according to the invention. The workstation 130 may also comprise a keyboard 131 and a mouse 132.

CLAIMS:

1. A method for extracting geometrical data from a 2-D digital image of the spine, comprising steps for determining spine outlines, wherein:

- digitizing the spine center line and end points of said spine center line;

- constructing a 2-D Rectangular-Band around said spine center line;

5 - processing the 2-D Rectangular-Band image data in order to estimate best paths going through selected points for determining the spine outlines.

2. A method as claimed in Claim 1, wherein the steps for constructing the Rectangular-Band comprises:

10 - constructing, in the 2-D digital image, a 2-D image band, referred to as Rubber-Band, whose center line is a spline representing the spine center line, and unfolding said Rubber-Band for constructing a 2-D Rectangular-Band; and

- calculating the intensities of the points of the Rectangular-Band from the intensities of the corresponding points of the Rubber-Band.

15

3. A method as claimed in one of Claims 1 or 2, wherein the step for estimating the spine outlines comprises estimating the best paths as lowest cost paths linking points selected by a contour detection operation optimizing a cost function composed of a local cost favoring the points having intensity characteristics that are optimum in the direction

20 orthogonal to the spine centerline and a transition cost which constrains the path to go smoothly from one point to a next point.

4. A method as claimed in Claim 3, wherein a prior knowledge relating to spine vertebra width and to spine length is used to optimize the local cost.

25

5. A method as claimed in one of Claims 3 or 4, wherein digitized guide-points are added to the found outline points to compel the best paths to go through them.

6.   A method as claimed in one of Claims 1 to 5, further comprising steps of
processing said 2-D rectangular image band image data in order to estimate spine endplates
locations using the data of one corresponding found spine outline.

5   7.   A method as claimed in Claim 6, wherein said steps comprise:
•   starting from the points of said corresponding found outline and determining twice the
     best path to reach the spine center line, a first time in following a upward edge gradient
     direction and a second time in following a downward edge gradient direction, and
•   storing the costs relating to said best paths.
10

8.   A method as claimed in Claim 7, wherein the best path to reach the spine
centerline is estimated by a contour detection operation optimizing a cost function composed
of a local cost favoring the points having intensity gradients that are optimum in the direction
parallel to the spine centerline and a transition cost which constrains the path to go smoothly
15   from one point to a next point.

9.   .   A method as claimed in one of Claims 7 or 8, further comprising steps of:
•   constructing a first and a second cost profiles for the upward and downward directions, at
     locations along the spine center line,
20 •   determining the up-endplates and down-endplates locations as respective minimum of the
     first and the second cost profiles, said locations being referred to as nodes.

10.   A method as claimed in Claim 9, for determining the respective nodes of the
cost profiles, comprising steps of:
25 •   adding initial knowledge of the number of endplates and of the location of the endplates
     of a first considered vertebra and of a last considered vertebra in the image, said locations
     being defined by points digitized on the spine centerline,
•   defining intervals, along the spine centerline, where it is probable to find an endplate, in
     the first and the second profiles, and defining standard deviations with respect to said
30   intervals, using a database knowledge,
•   assigning a label of first endplate to the first node, and labeling progressively the nodes to
     the last endplate, thus determining by accumulating standard deviations, several nodes to .
     said last endplate,

• redefining the appropriate label to the last node by using the initial knowledge of the last endplate location and correcting the labeling of the previous nodes accordingly by backtracking toward the first node.

5   11.   A method as claimed in one of Claims 6 to 10, further comprising steps of determining points of the spine, referred to as corners of vertebrae, located at the intersection of the outlines and the endplates.

12.   A method as claimed in Claim 11, further comprising steps of digitizing guide

10   points that are set on the corners of the vertebrae to improve the labeling of the nodes.

13.   A method as claimed in one of Claims 1 to 12, comprising previous normalization of the point gradients within a range of gradient values to compensate for possible undue differences of brightness in regions of the original image.

15

14.   An imaging system having acquisition means for acquiring images of the spine, having display means to display said images, having interactive drawing means to digitize the spine center line, the end points and guide points, having storage means to store the initial knowledge and database knowledge, storage means to store image data, and having

20   processing means to carry out a method as claimed in one of Claims 1 to 13.

15.   An imaging system as claimed in Claim 14, wherein the processing means comprise a suitably programmed computer of a workstation or a special purpose processor having circuit means, which are arranged to process the image data, and wherein the display

25   means displays the processed images.

16.   A medical examination apparatus having the system of one of Claims 14 or 15.

30   17.   A computer program product comprising a set of instructions for carrying out the method as claimed in one of Claims 1 to 13.

1/8
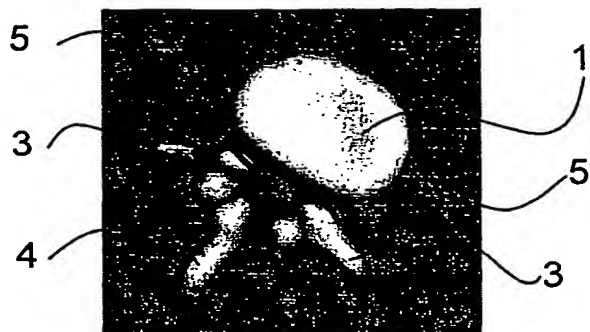
FIG.1A

FIG.1B
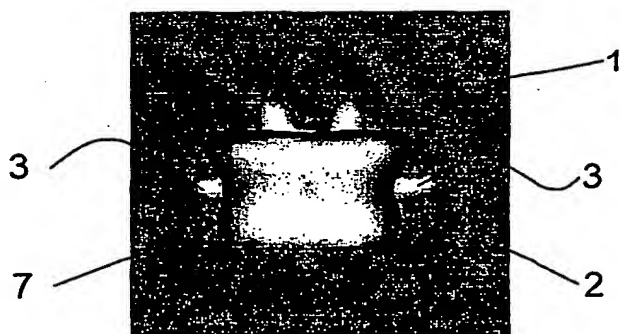
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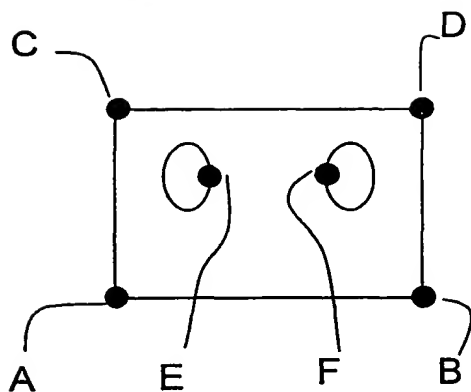
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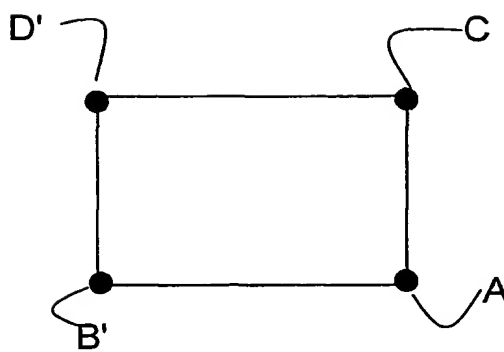
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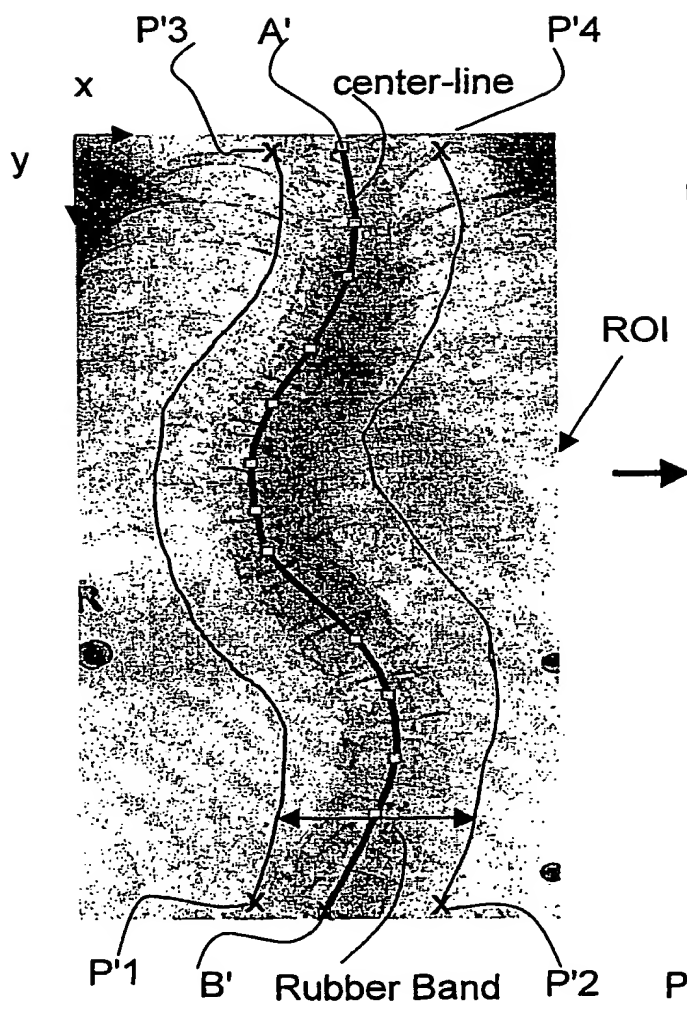
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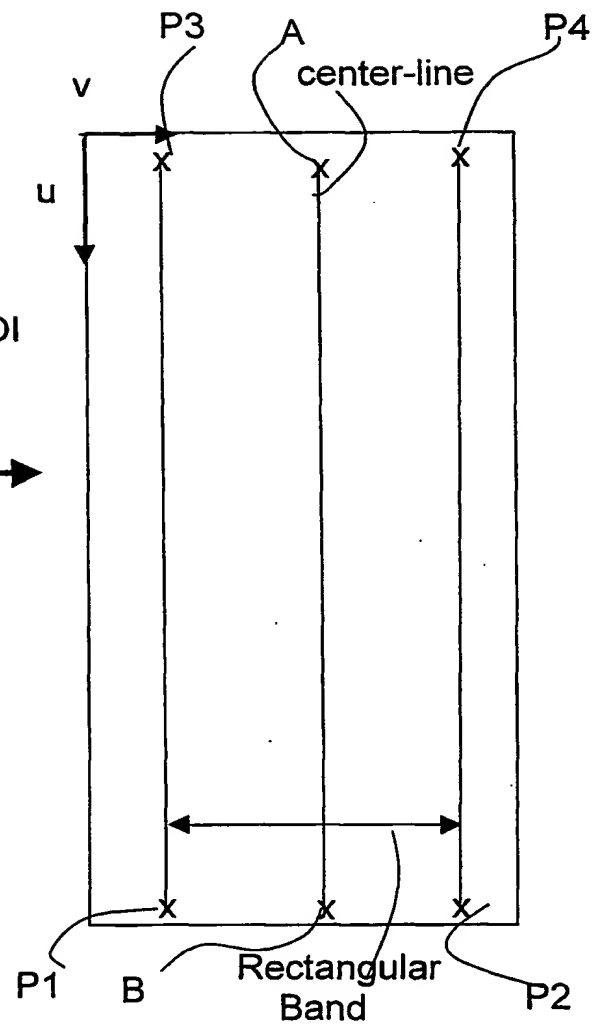
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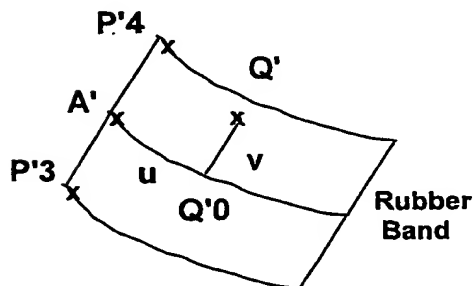
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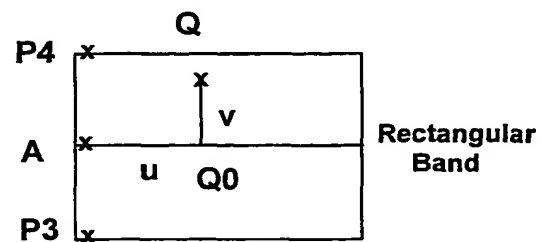
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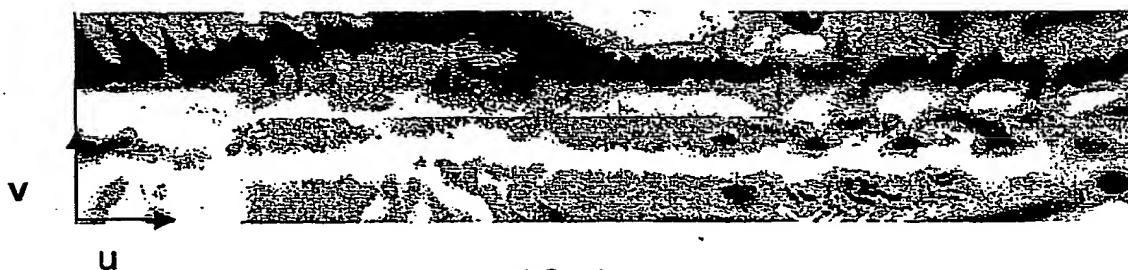
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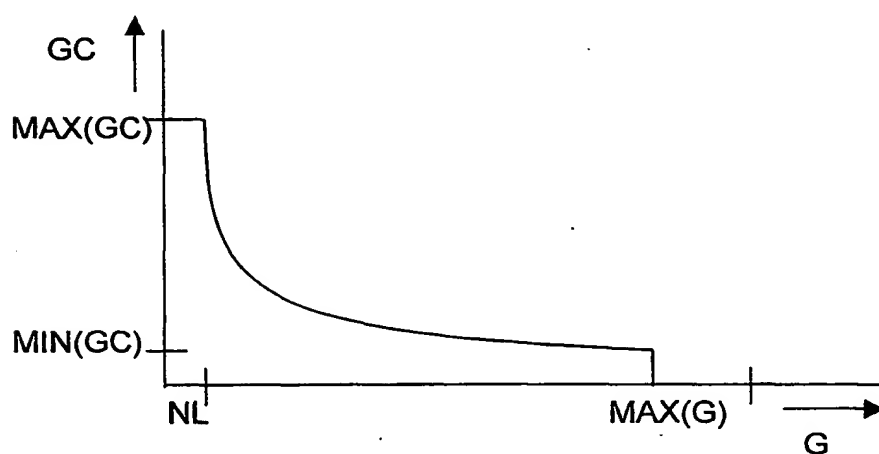
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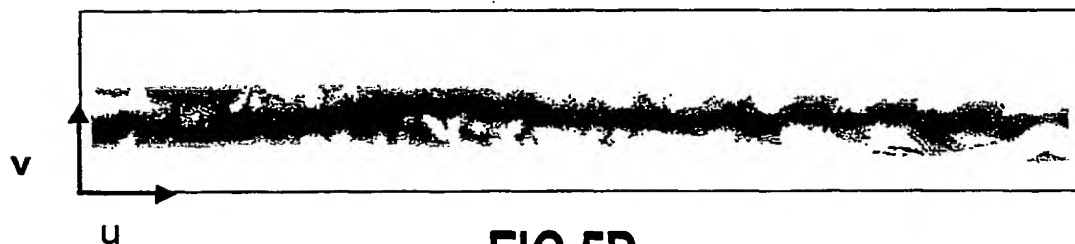
FIG.5B

FIG.8A

FIG.8B
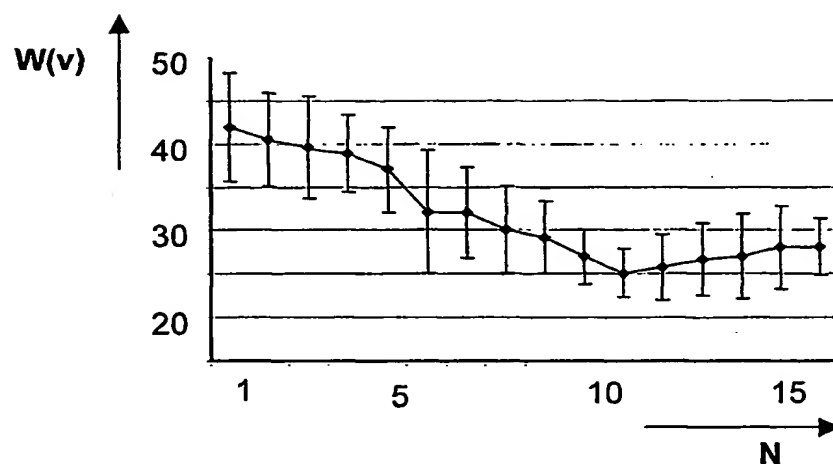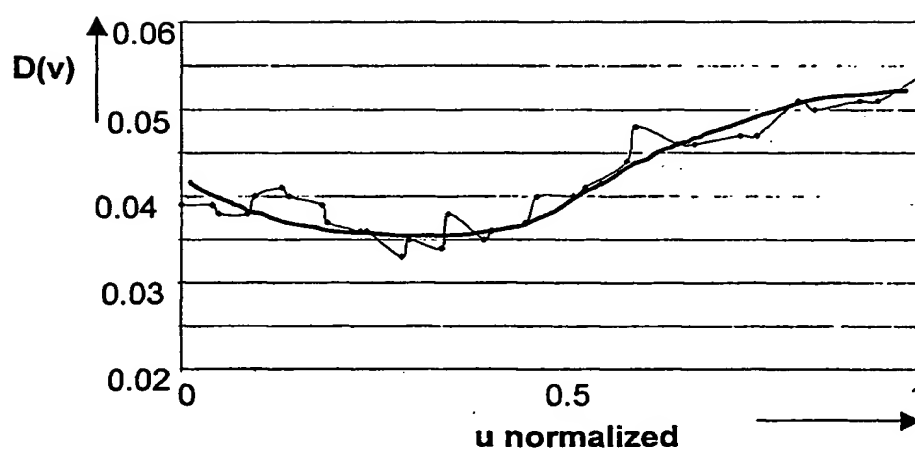
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FIG.6A

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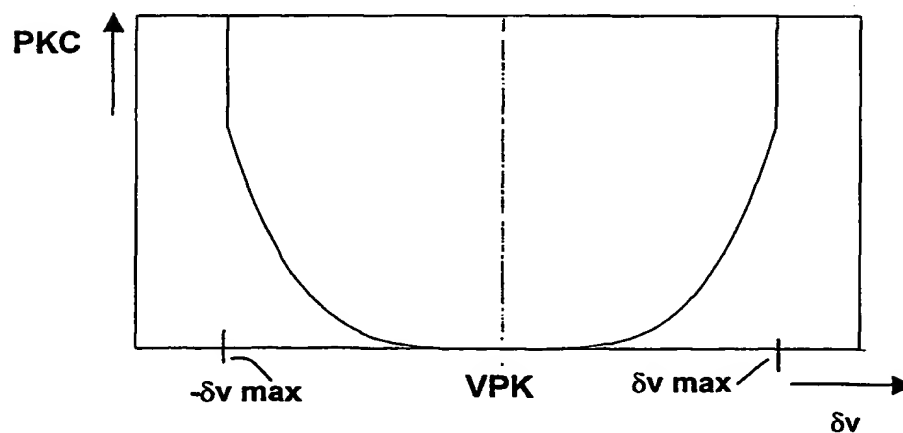
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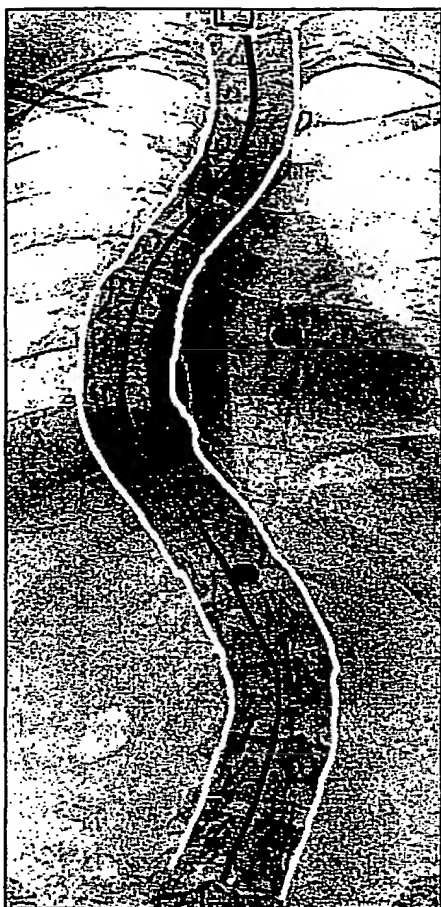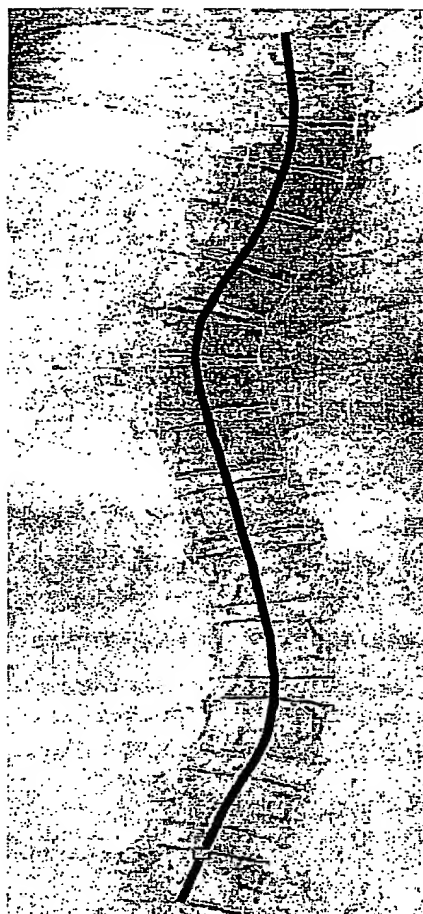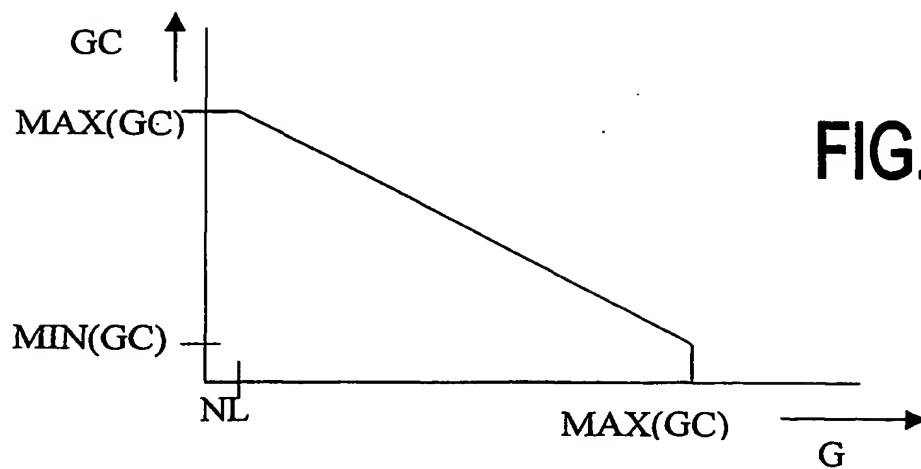
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FIG.7

FIG.14

FIG.9

FIG.10

FIG.11A

FIG.11B
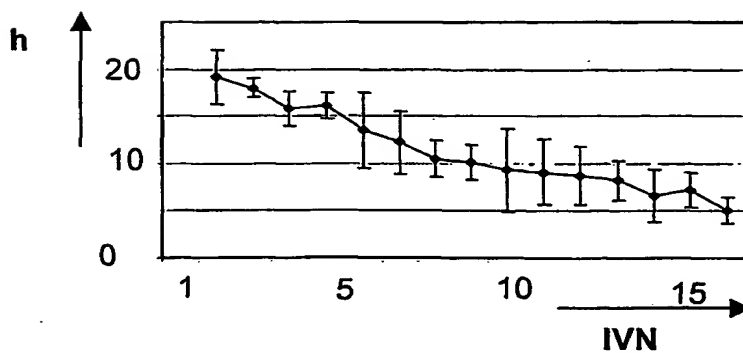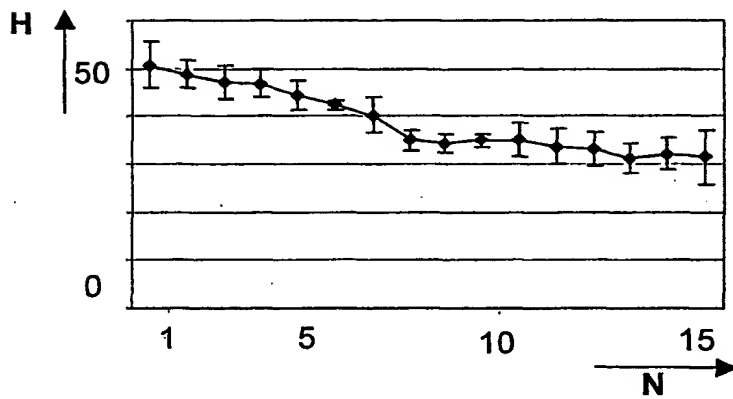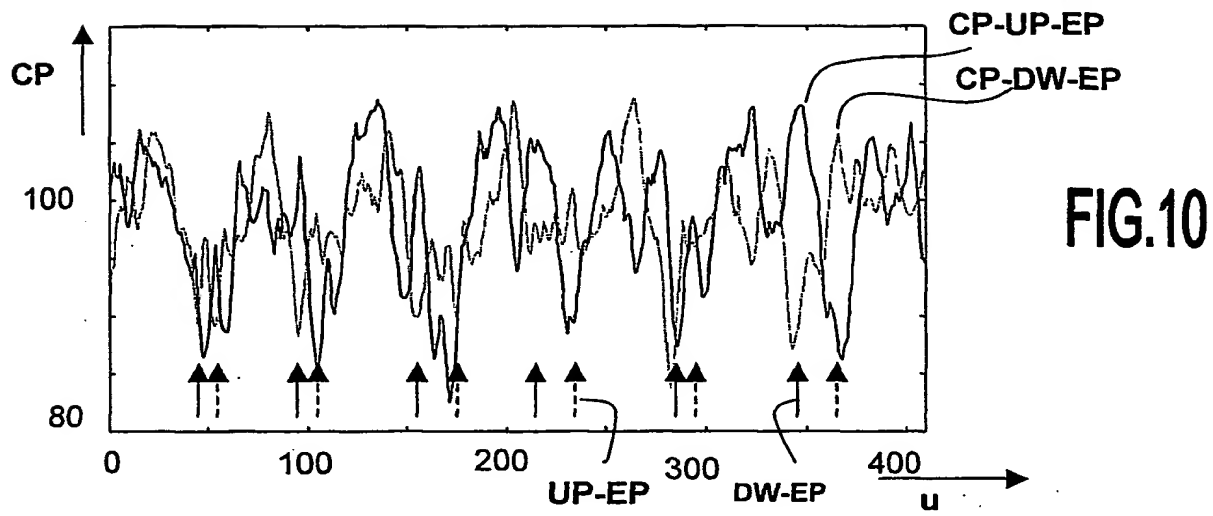
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FIG.12A

FIG.15

U9/936824
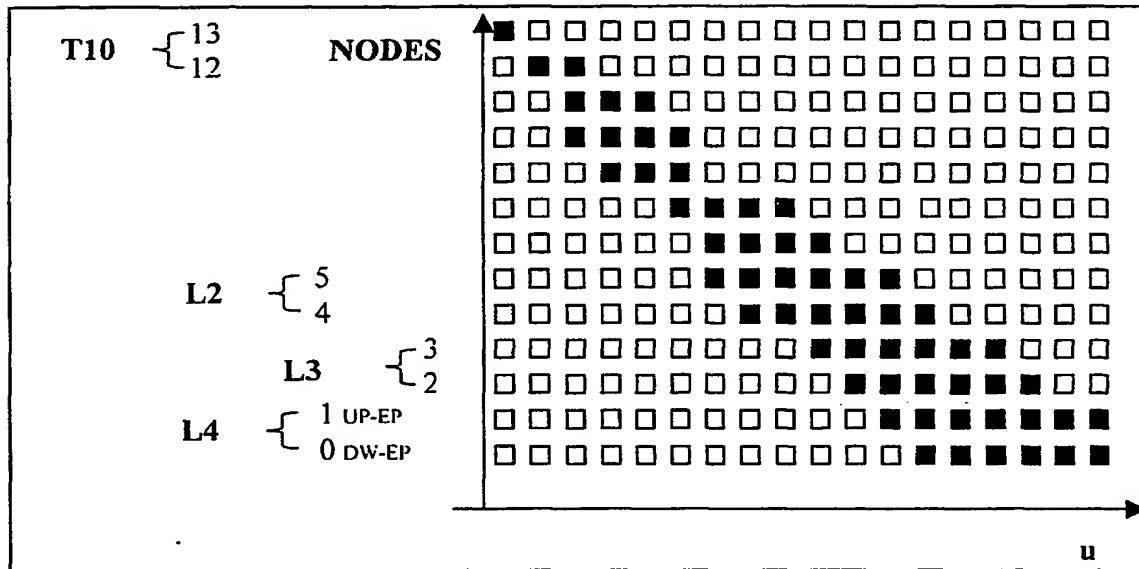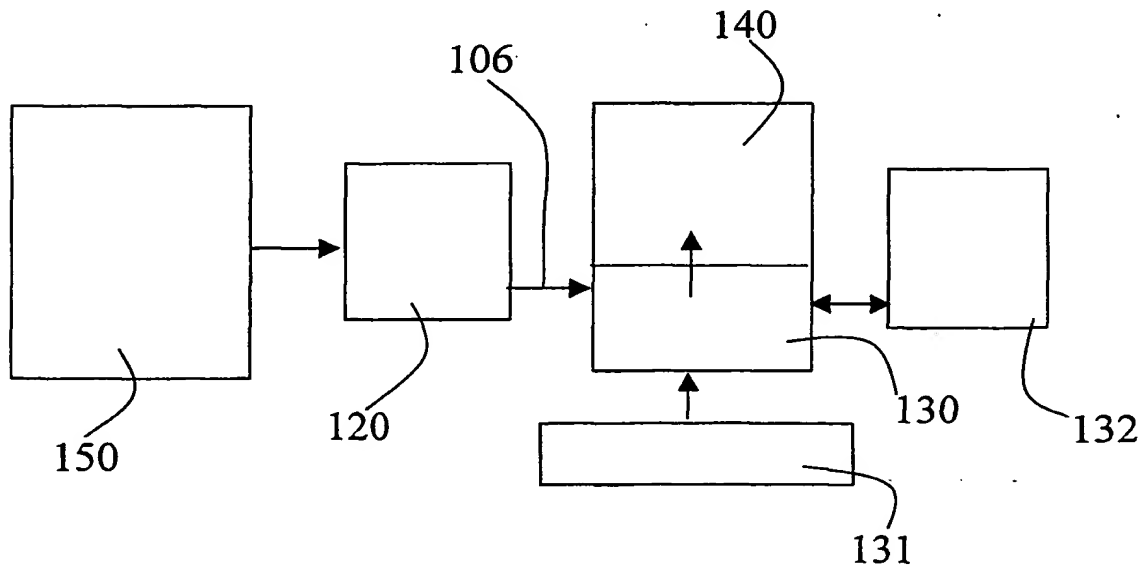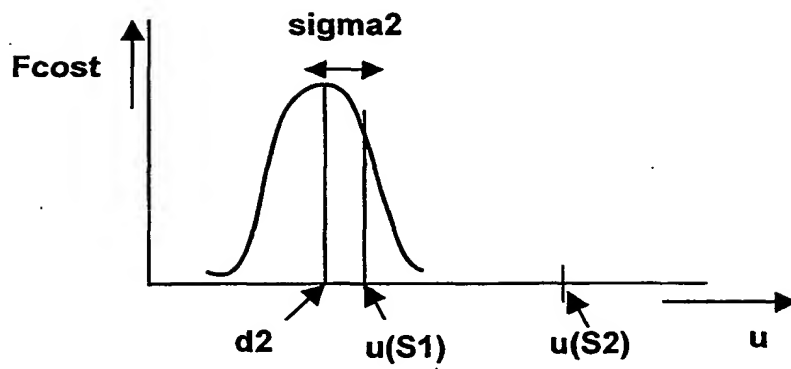
FIG.12B

FIG.13A

FIG.13B

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PATENT COOPERATION TREATY
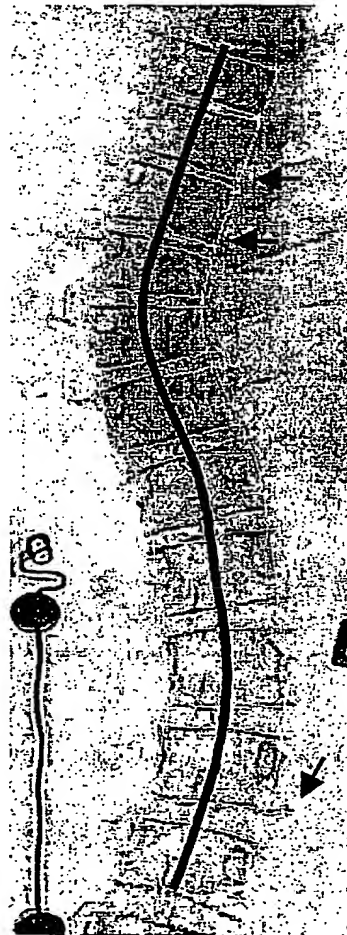
2 6 JUL 2001

INTERNATIONAL SEARCHING AUTHORITY

INTERNATIONAAL OCTROOIBUREAU B.V
Attn. Lottin, Claudine
PROF. HOLSTLAAN 6
NL-5656 AA EINDHOVEN
NETHERLANDS

L OTT

PCT

NOTIFICATION OF TRANSMITTAL OF
THE INTERNATIONAL SEARCH REPORT
OR THE DECLARATION

(PCT Rule 44.1)

Date of mailing (day/month/year)	27/07/2001

Applicant's or agent's file reference	FOR FURTHER ACTION	See paragraphs 1 and 4 below
PHFR000095WO		

International application No.	International filing date (day/month/year)
PCT/EP 01/00771	24/01/2001

Applicant

KONINKLIJKE PHILIPS ELECTRONICS N.V.

1. [X] The applicant is hereby notified that the International Search Report has been established and is transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the International Application (see Rule 46):

   When? The time limit for filing such amendments is normally 2 months from the date of transmittal of the International Search Report; however, for more details, see the notes on the accompanying sheet.

   Where? Directly to the   International Bureau of WIPO
   34, chemin des Colombettes
   1211 Geneva 20, Switzerland
   Fascimile No.: (41-22) 740.14.35

   For more detailed instructions, see the notes on the accompanying sheet.

2. [ ] The applicant is hereby notified that no International Search Report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. [ ] **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

   [ ] the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

   [ ] no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Further action(s):**   The applicant is reminded of the following:

   Shortly after **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

   Within **19 months** from the priority date, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase until 30 months from the priority date (in some Offices even later).

   Within **20 months** from the priority date, the applicant must perform the prescribed acts for entry into the national phase before all designated Offices which have not been elected in the demand or in a later election within 19 months from the priority date or could not be elected because they are not bound by Chapter II.

Name and mailing address of the International Searching Authority	Authorized officer
European Patent Office, P.B. 5818 Patentiaan 2 NL-2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Cornelia Schulze

Form PCT/ISA/220 (July 1998)

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INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference PHFR000095WO	**FOR FURTHER ACTION**	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
International application No. PCT/EP 01/00771	International filing date *(day/month/year)* 24/01/2001	(Earliest) Priority Date *(day/month/year)* 27/01/2000

Applicant KONINKLIJKE PHILIPS ELECTRONICS N.V.

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of _____3_____ sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

      [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

      [ ] contained in the international application in written form.

      [ ] filed together with the international application in computer readable form.

      [ ] furnished subsequently to this Authority in written form.

      [ ] furnished subsequently to this Authority in computer readble form.

      [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

      [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable (See Box I).**

3. [ ] **Unity of invention is lacking (see Box II).**

4. With regard to the **title,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No.   3a

   [ ] as suggested by the applicant.   [ ] None of the figures.

   [X] because the applicant failed to suggest a figure.

   [ ] because this figure better characterizes the invention.

Form PCT/ISA/210 (first sheet) (July 1998)

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   G06T7/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 841 833 A (GAUNTT DAVID M ET AL) 24 November 1998 (1998-11-24) abstract column 11, line 24 - line 31	1,3, 14-17
Y	figure 19	2
Y	WO 99 52068 A (KONINKL PHILIPS ELECTRONICS NV ;PHILIPS SVENSKA AB (SE)) 14 October 1999 (1999-10-14) abstract page 7, line 3 - line 6	2

-/--

| X | Further documents are listed in the continuation of box C. | | X | Patent family members are listed in annex. |

° Special categories of cited documents :

'A' document defining the general state of the art which is not considered to be of particular relevance

'E' earlier document but published on or after the international filing date

'L' document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

'O' document referring to an oral disclosure, use, exhibition or other means

'P' document published prior to the international filing date but later than the priority date claimed

'T' later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

'X' document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

'Y' document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

'&' document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 July 2001	27/07/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	González Arias, P

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	KAUFFMANN C ET AL: "DIGITAL RADIOGRAPHY SEGMENTATION OF SCOLIOTIC VERTEBRAL BODY USING DEFORMABLE MODELS" PROCEEDINGS OF THE SPIE, 1997, XP000869811 cited in the application the whole document ---	1-17
A	US 5 533 084 A (MAZESS RICHARD B) 2 July 1996 (1996-07-02) abstract ---	1-17
A	EP 0 743 618 A (UNIV BRISTOL) 20 November 1996 (1996-11-20) abstract -----	1-17
C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.

1

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Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 5841833	A	24-11-1998	US	5306306 A	26-04-1994
			US	5509042 A	16-04-1996
			US	5291537 A	01-03-1994
			US	5228068 A	13-07-1993
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			WO	9406351 A	31-03-1994
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WO 9952068	A	14-10-1999	EP	0990222 A	05-04-2000
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Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 5533084	A		US US US US EP JP	RE36162 E 5287546 A 5306306 A 5480439 A 0755219 A 9511418 T	23-03-1999 15-02-1994 26-04-1994 02-01-1996 29-01-1997 18-11-1997
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